Fremtidens vindenergi – en magisters historie på Risø og DTU

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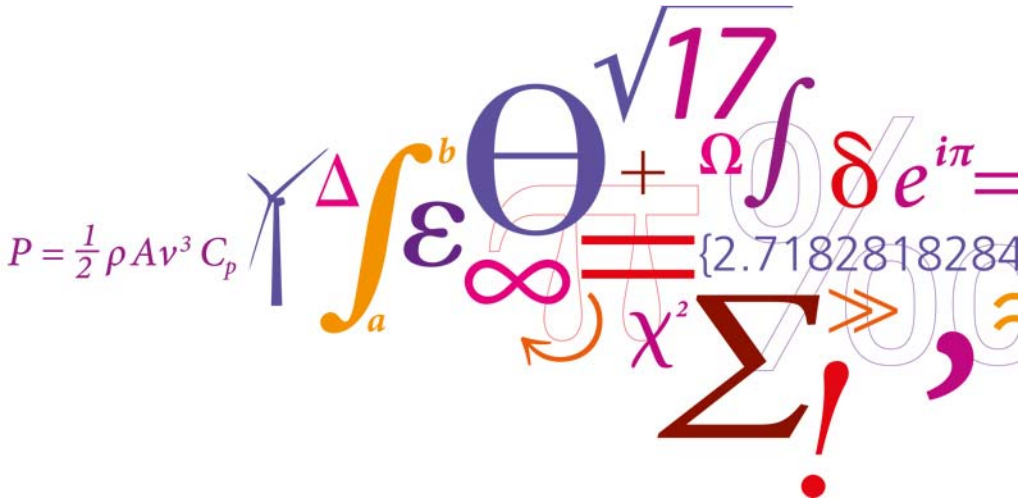
Niels G. Mortensen
Meteorologisektionen



DTU Vindenergi
Institut for Vindenergi

Oplæg

- Hvordan havner en naturgeograf på Risø / DTU?
  - Hvad arbejder jeg med inden for vindenergi?

- Hvordan vi fik samarbejdspartnere og kunder i over 100 lande!
  - Historien om European Wind Atlas og WAsP

- Hvad skal der egentlig til for at kortlægge verdens vindressourcer?
  - Det har taget over 30 år, men endelig er vi ved at være der!

Hvordan havner en naturgeograf på Risø og DTU?

Og hvad arbejder jeg med inden for vindenergi?

Niels Gylling Mortensen

Hvornår	Hvor og hvad
1970-72	Rungsted Statsskole *Student*
1975-85	Geografisk Institut, Københavns Universitet *Studerende, instruktor, undervisningsassistent, cand.scient.*
1985-96	Forskningscenter Risø, Roskilde *Forsker*
1992	National Center for Atmospheric Research, Boulder, Colorado *Gæsteforsker*
1997-2007	Forskningscenter Risø, Roskilde *Seniorforsker, tillidsrepræsentant, Risøs bestyrelse (2004-07)*
2008-	Danmarks Tekniske Universitet, Risø Campus, Roskilde *Seniorforsker i DTU Wind Energy*

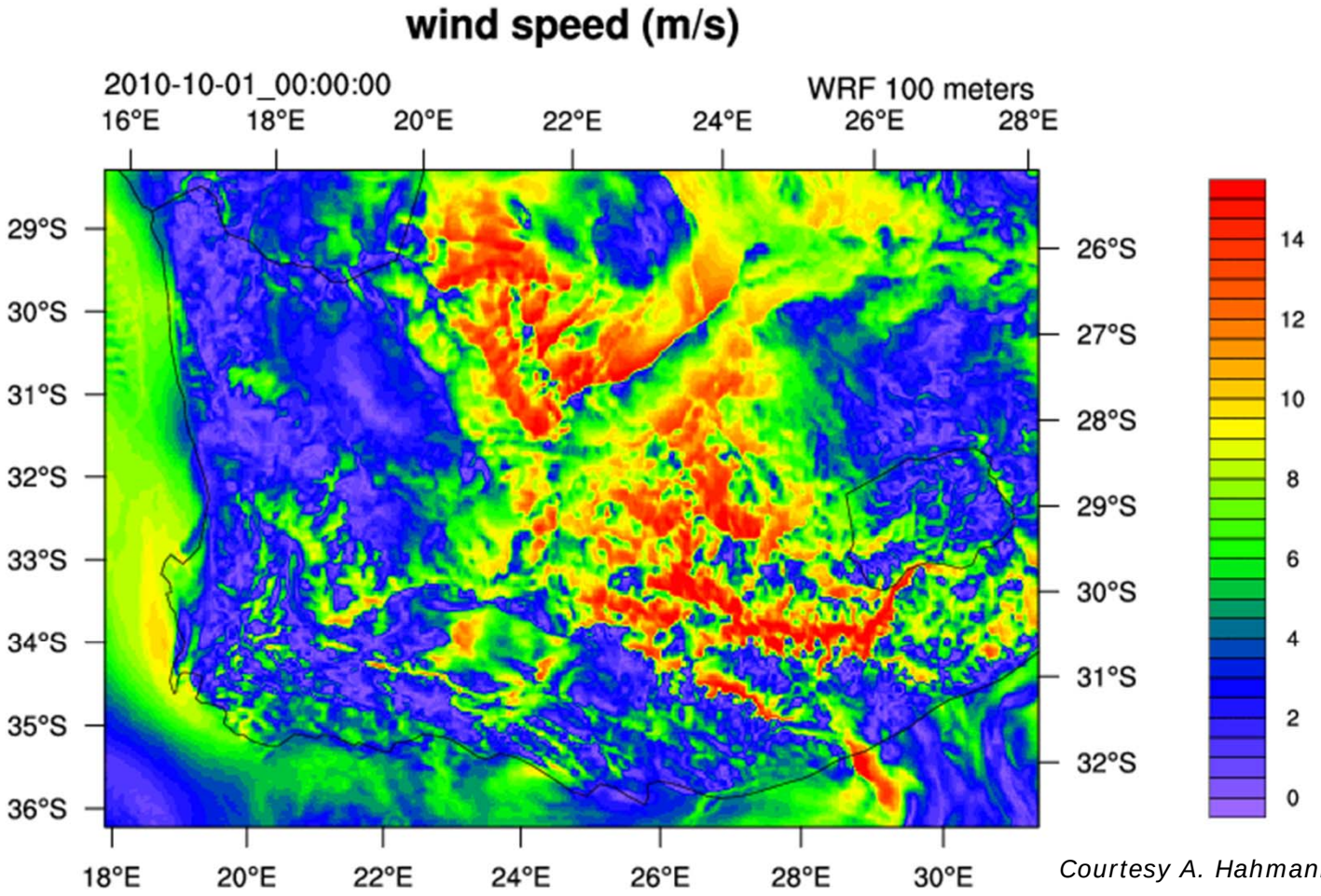
Niels Gylling Mortensen

- MSc (Phys. Geography) 1985 from University of Copenhagen
- 30 years at Risø and DTU, working with meteorological data and sensors, sonic anemometry, boundary layer meteorology, wind climatology and wind atlas, wind resource estimation and siting.
- Member of the WAsP development team since 1985
- Editor of European Wind Atlas (1989), Atlas Vent de l'Algérie, Wind Atlas for the Gulf of Suez, Wind Atlas for Egypt, Wind Atlas for NE China (Dongbei), Wind Atlas for South Africa.
- Consulting services in the European Union, as well as in Cape Verde, Morocco, Algeria, Egypt, India, Indonesia, Greenland, USA and Australia.
- Teaching at DTU since 2008: courses 46200 and 46300
- Teaching commercial (WAsP) courses since 1991

Typiske arbejdsområder

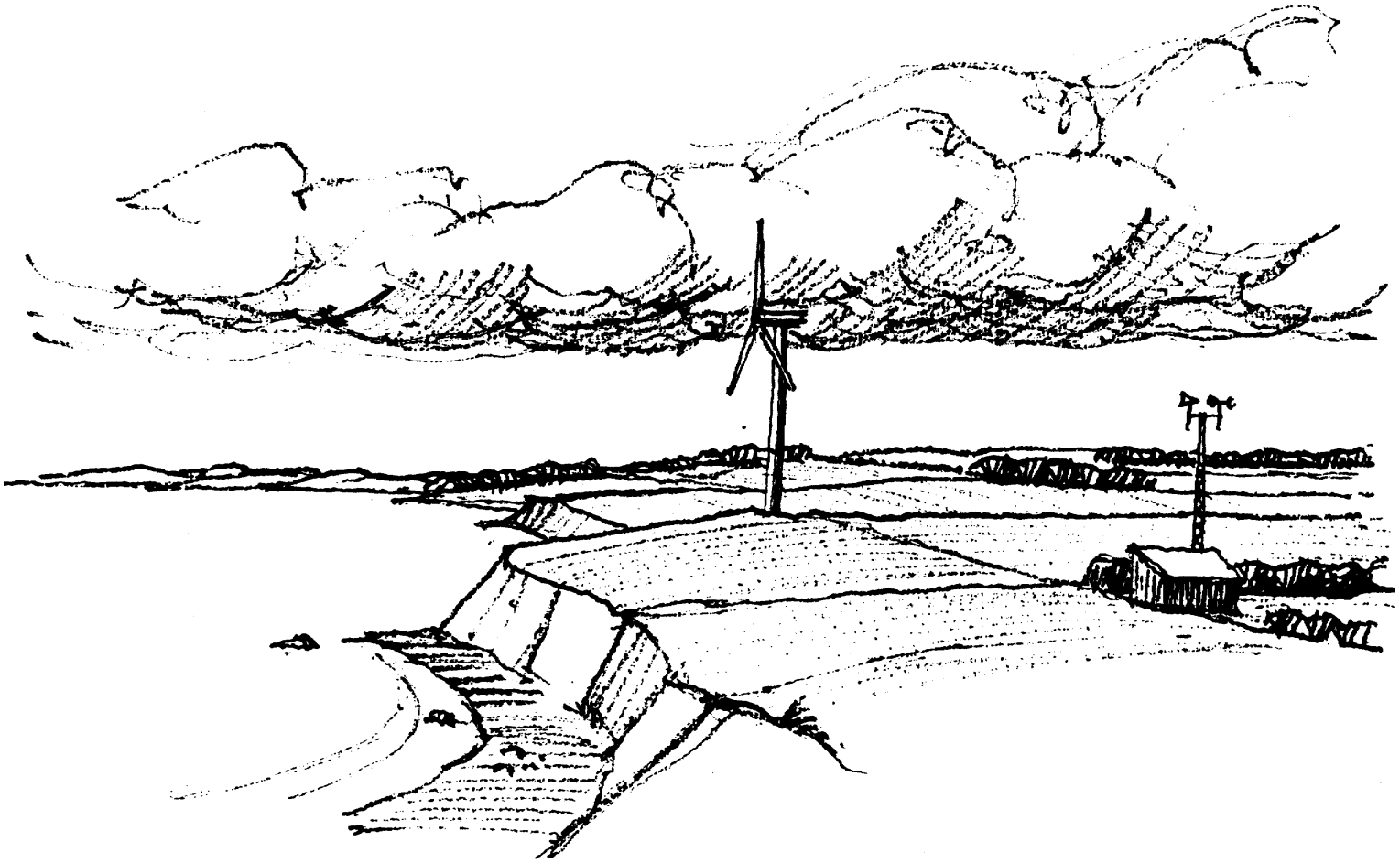
- Forskning og udvikling (40%)
  - Programforskning
  - Artikler og rapporter
  - Konferencer + papers
  - Netværk (standardisering)
  - Int. forskningssamarbejder
- Undervisning (20%)
  - *Introduktion til vindenergi*
  - *Planlægning og udvikling af vindmølleparker*
  - DTU efteruddannelse:
    WAsP standard kursus
    WAsP online kursus
    Offshore Wind Energy Technical Course
- Forskningsbaseret rådgivning
  - European Investment Bank
  - Government of South Africa
  - Province of Western Cape
  - Samarbejde med industrien
  - Energistyrelsen
- Innovation/kommercielt (40%)
  - Udvikling af WAsP software
  - Udvikling af anden software
  - Virtual Campus Hub (EU)
  - Measnet guidelines og certificering
- Arbejdsområder generelt
  - Vindkraftmeteorologi
  - Wind resource assessment

Wind flow over South Africa during 10 days in 2010



Courtesy A. Hahmann, DTU

The classic problem



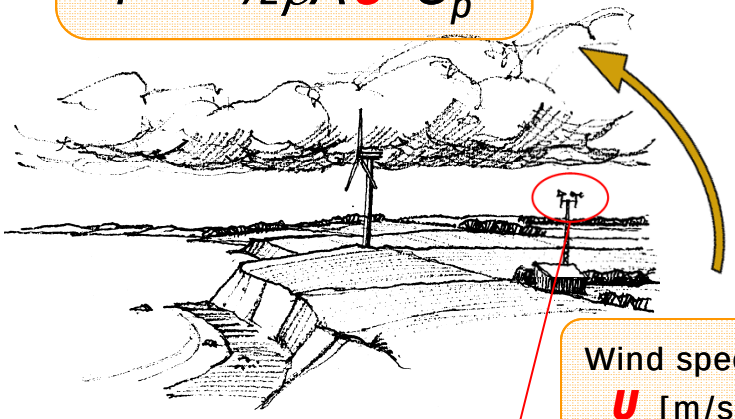
Wind resource assessment

Wind provides the income in cost-benefit

- Investment costs
- Operation and maintenance costs
- Electricity production ~ Wind resources
- Turbine lifetime
- Discount rate
- Environmental benefits

Power in the wind

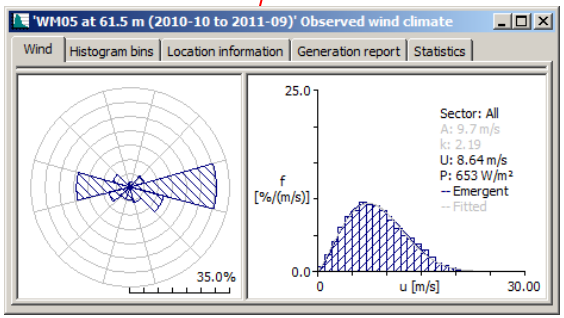
$$P = \tfrac{1}{2}\rho A U^3 C_p$$



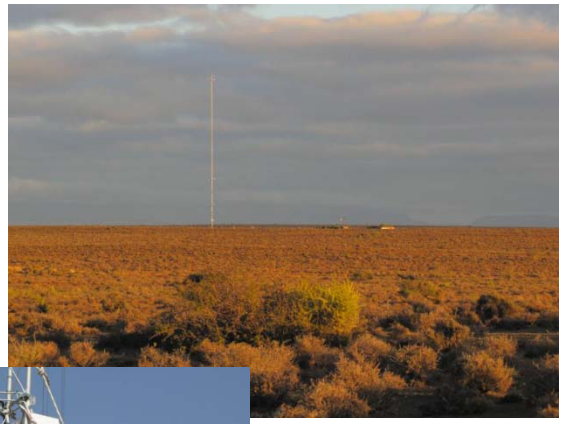
Wind speed
U [m/s]

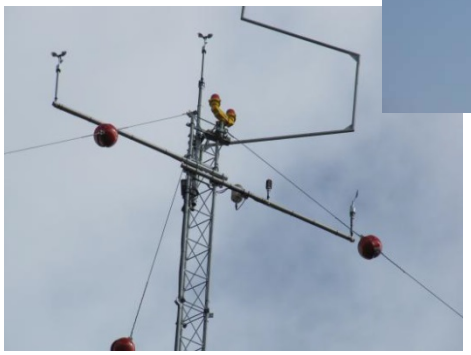
10% error on wind speed ⇨ up to 30% error on energy

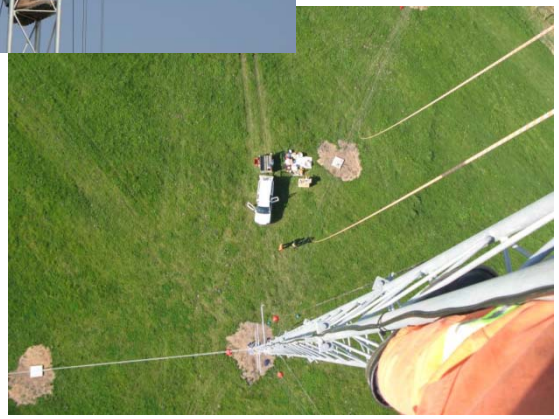
Modelling is necessary and it must be good!



A great job…on a good day





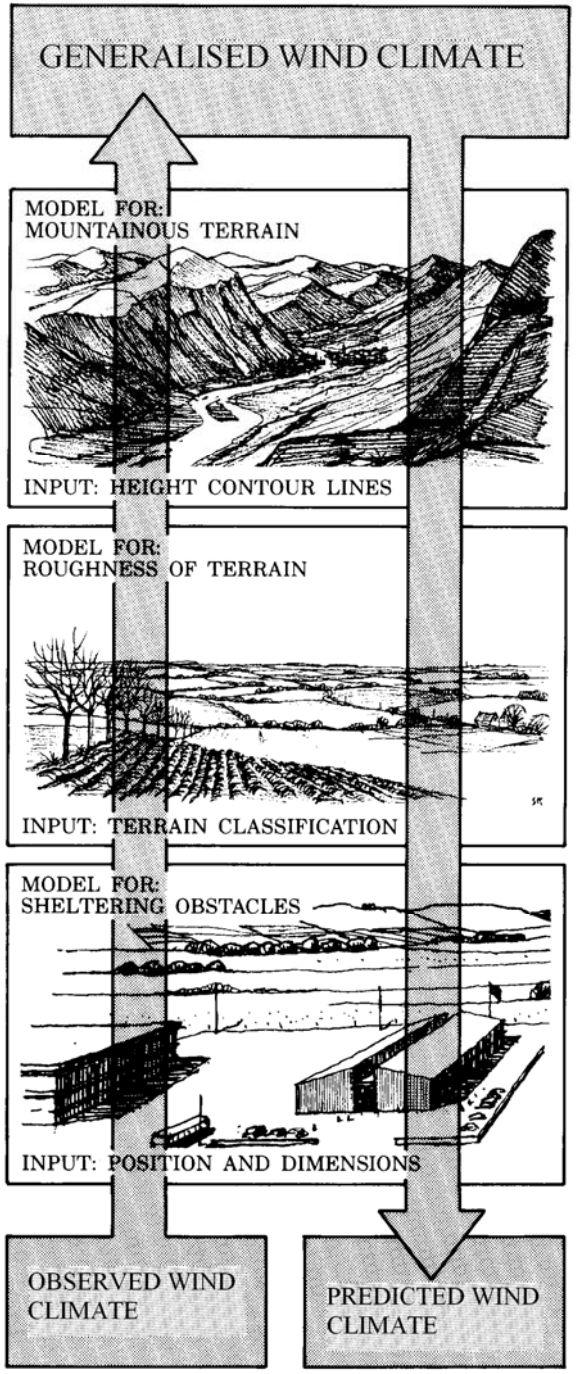


Samarbejdspartnere og kunder i over 100 lande!

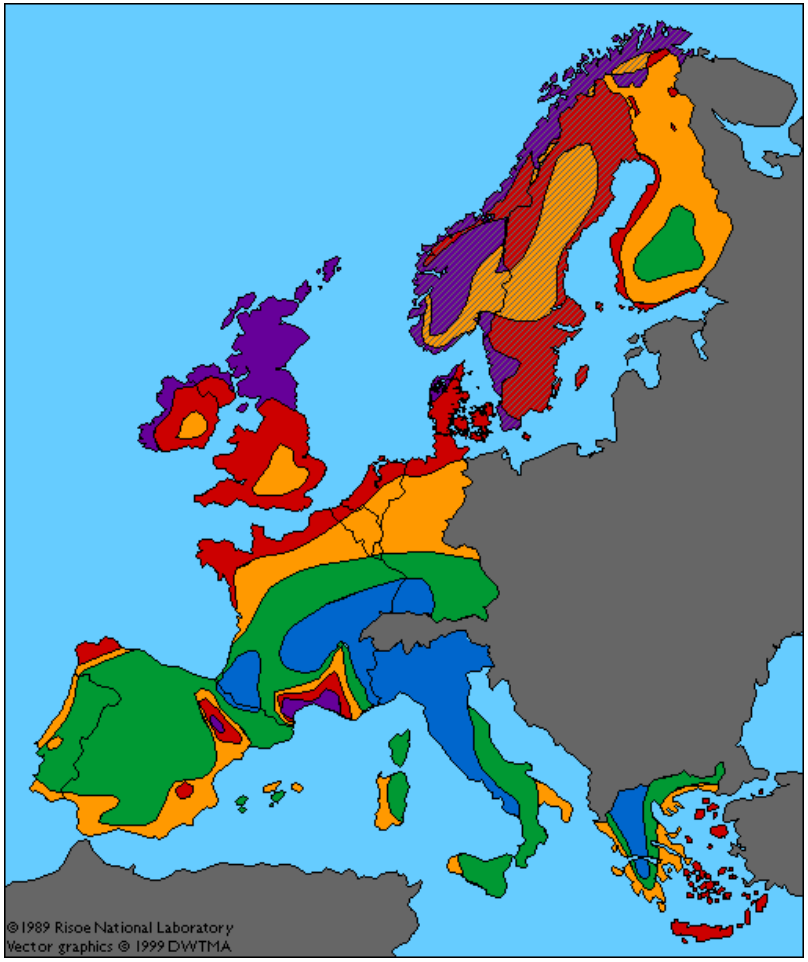
European Wind Atlas og WAsP programmet

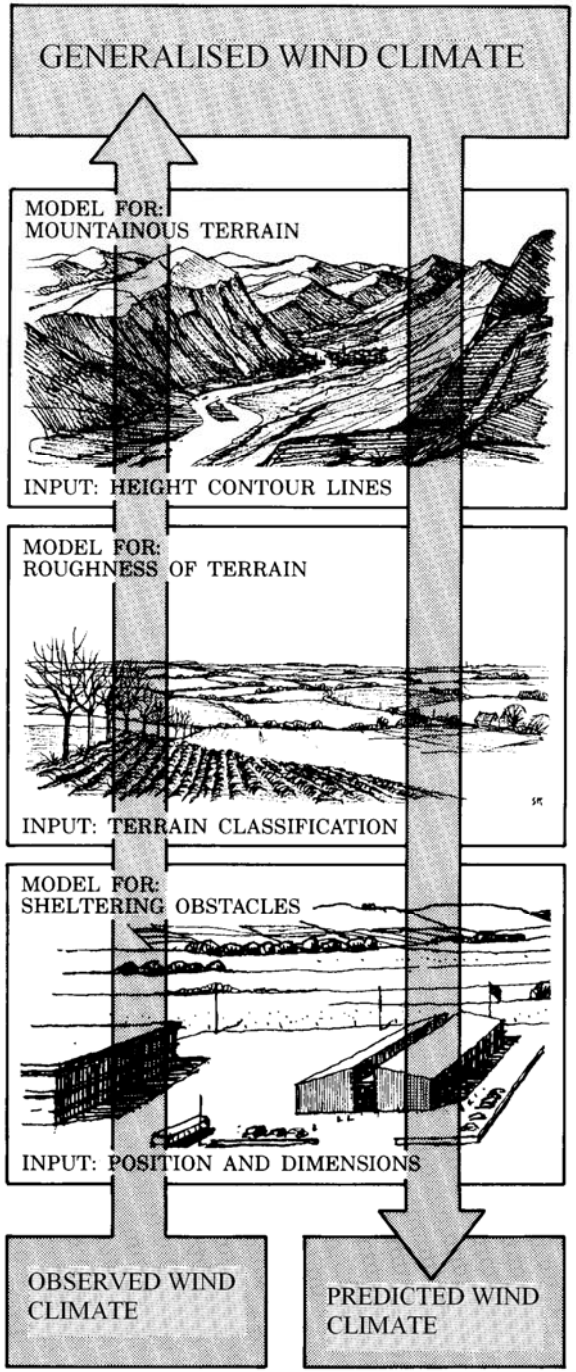
Wind atlas methodology

- Challenge
  - Extrapolate wind climatologies from masts to wind turbines
  - Solution: flow modelling (WAsP)
- Input data
  - Wind climatology
  - Terrain elevation
  - Land cover
  - Sheltering obstacles
- Results
  - Wind climate estimation
  - Wind turbine production
  - Wind farm annual yield
  - Wind resource mapping

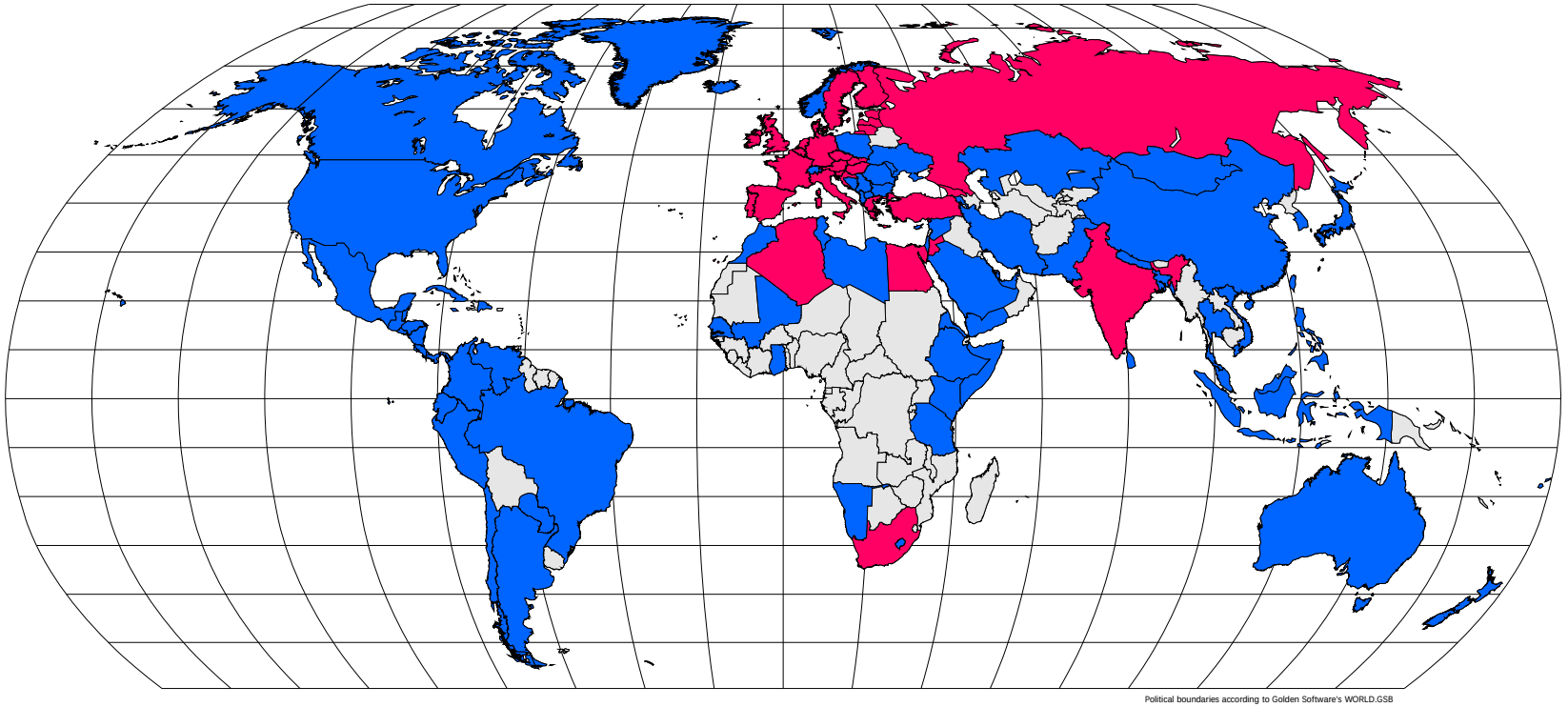


Wind atlas methodology



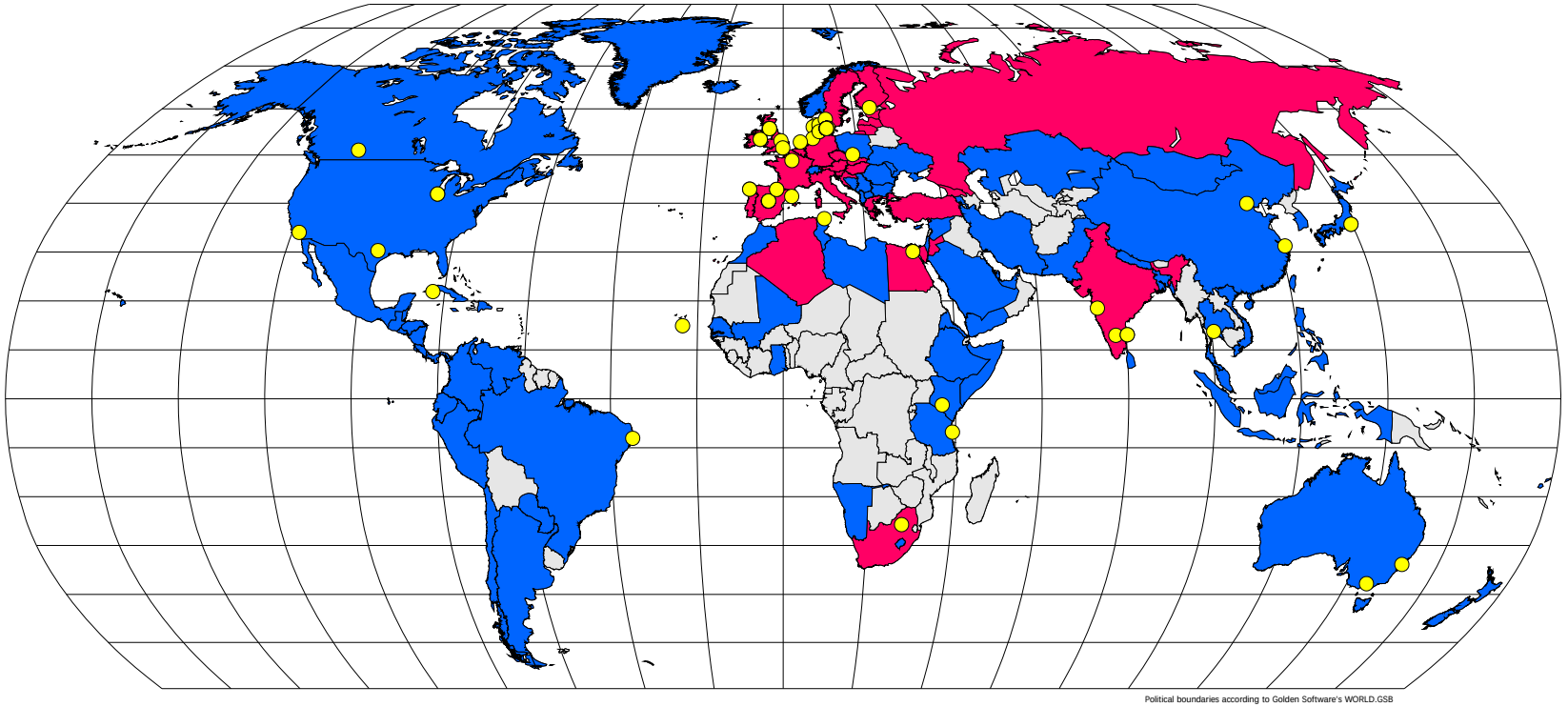


The world according to WAsP



- WAsP software since 1987
- 4500+ licensed users by now
- WAsP also in WindFarmer (DNV-GL) and WindPRO (EMD) + Wind Farm (ReSoft)
- 110 countries and territories
- National wind atlases… ■
- Regional and local studies… ■

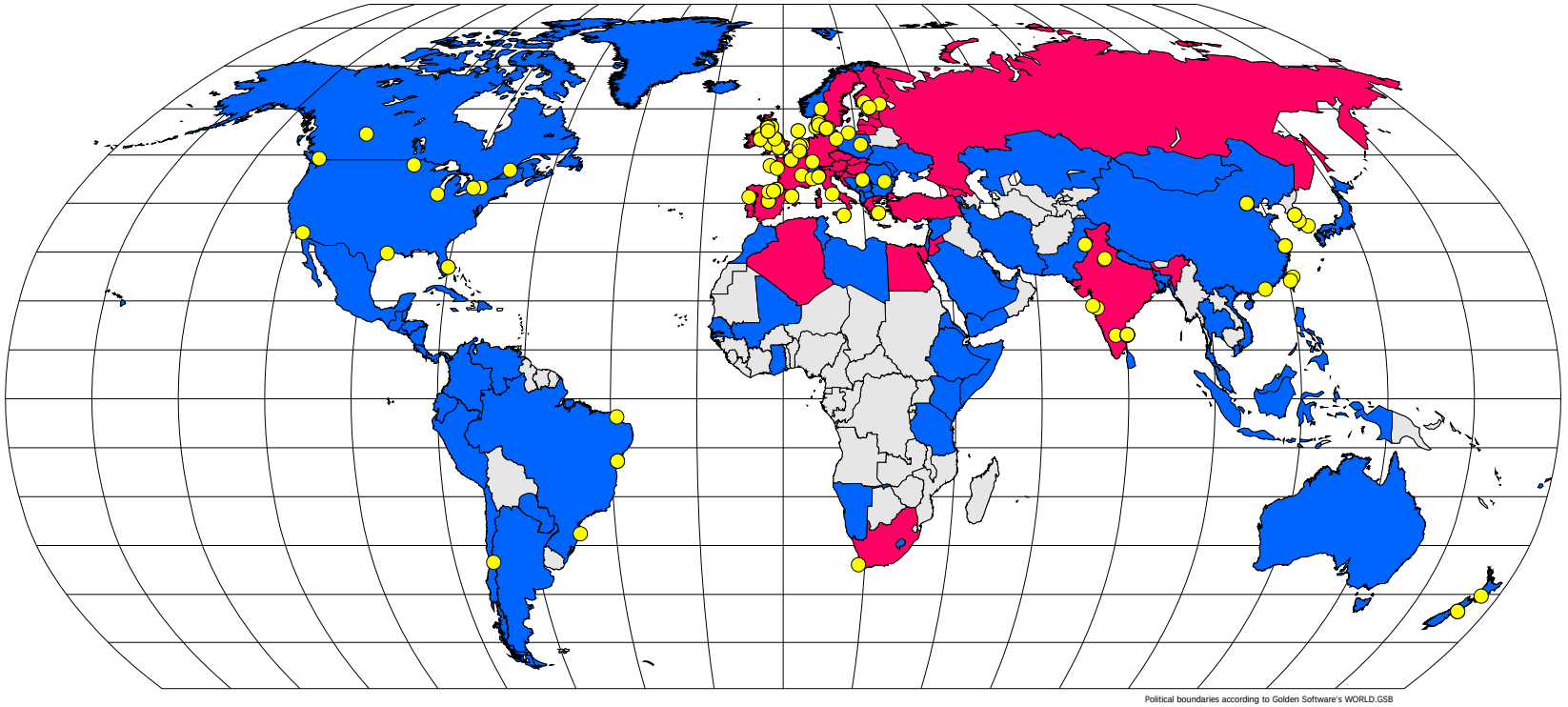
WAsP courses



- WAsP courses since 1991
- 101 courses held by now
- More than 1500 users trained

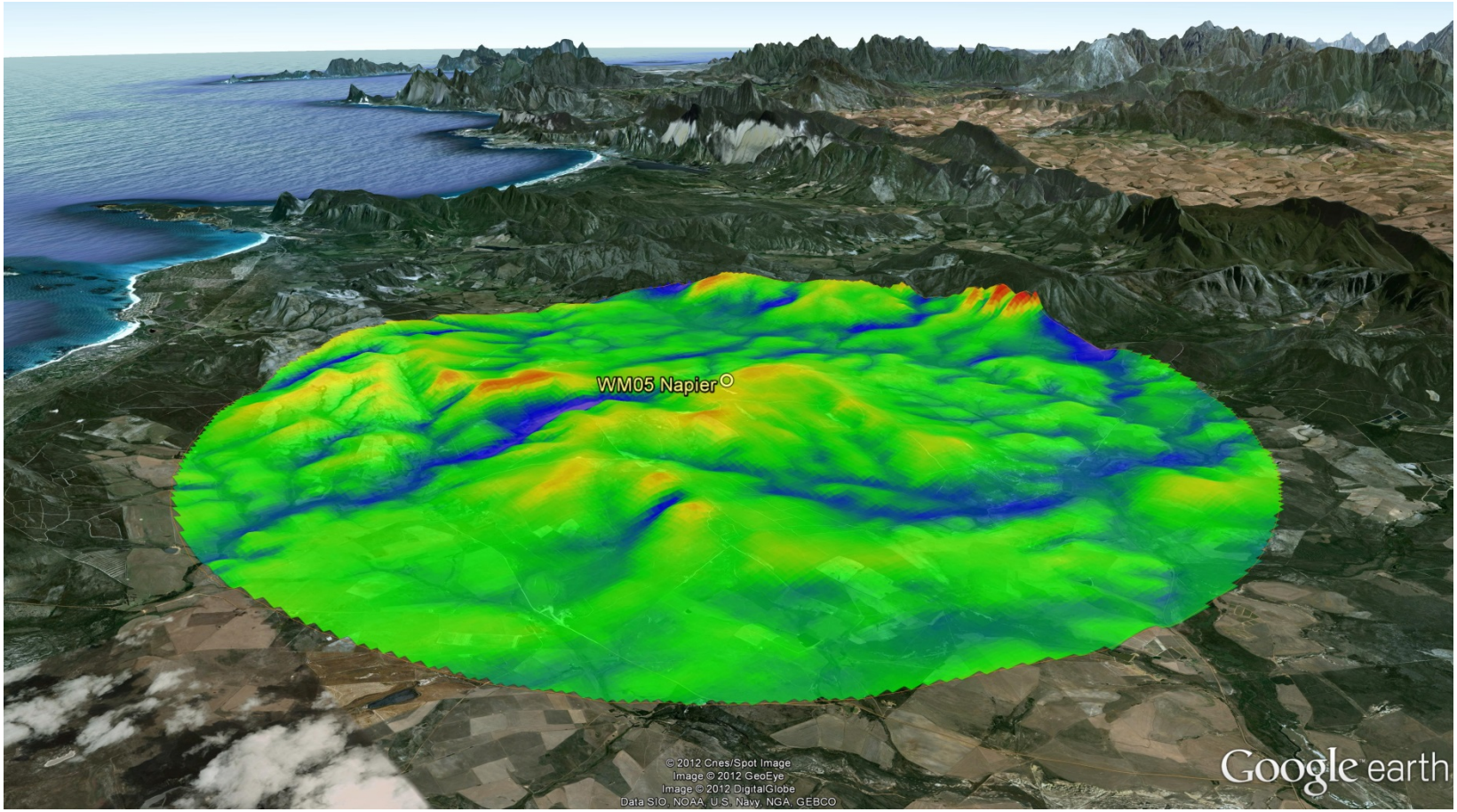
- WAsP course venues...
- 25 countries

WAsP certified users

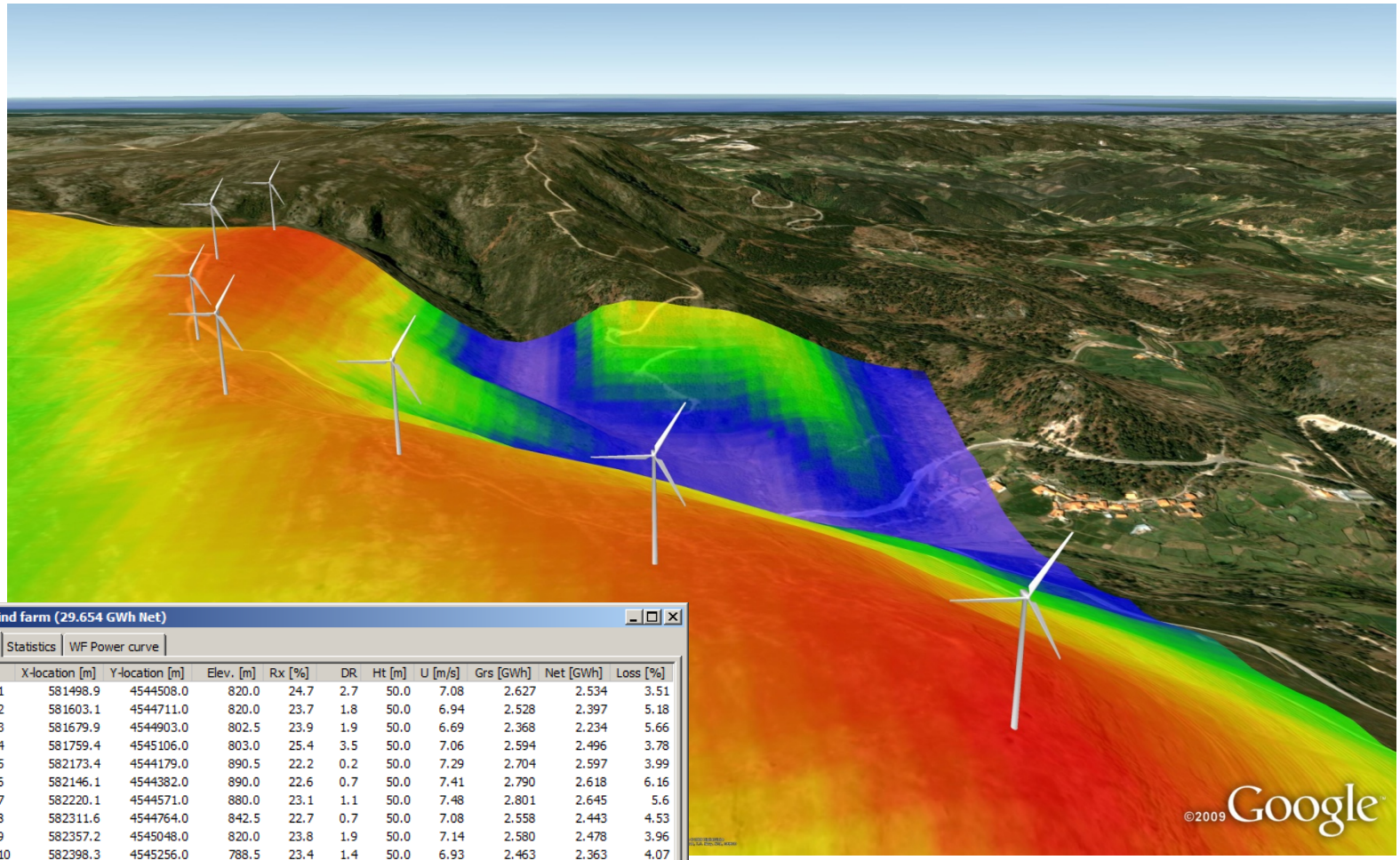


- WAsP certification since 2001
- More than 230 certified users
- Certified users...
- 29 countries

Wind predictions around a mast



Wind farm Annual Energy Production (AEP)



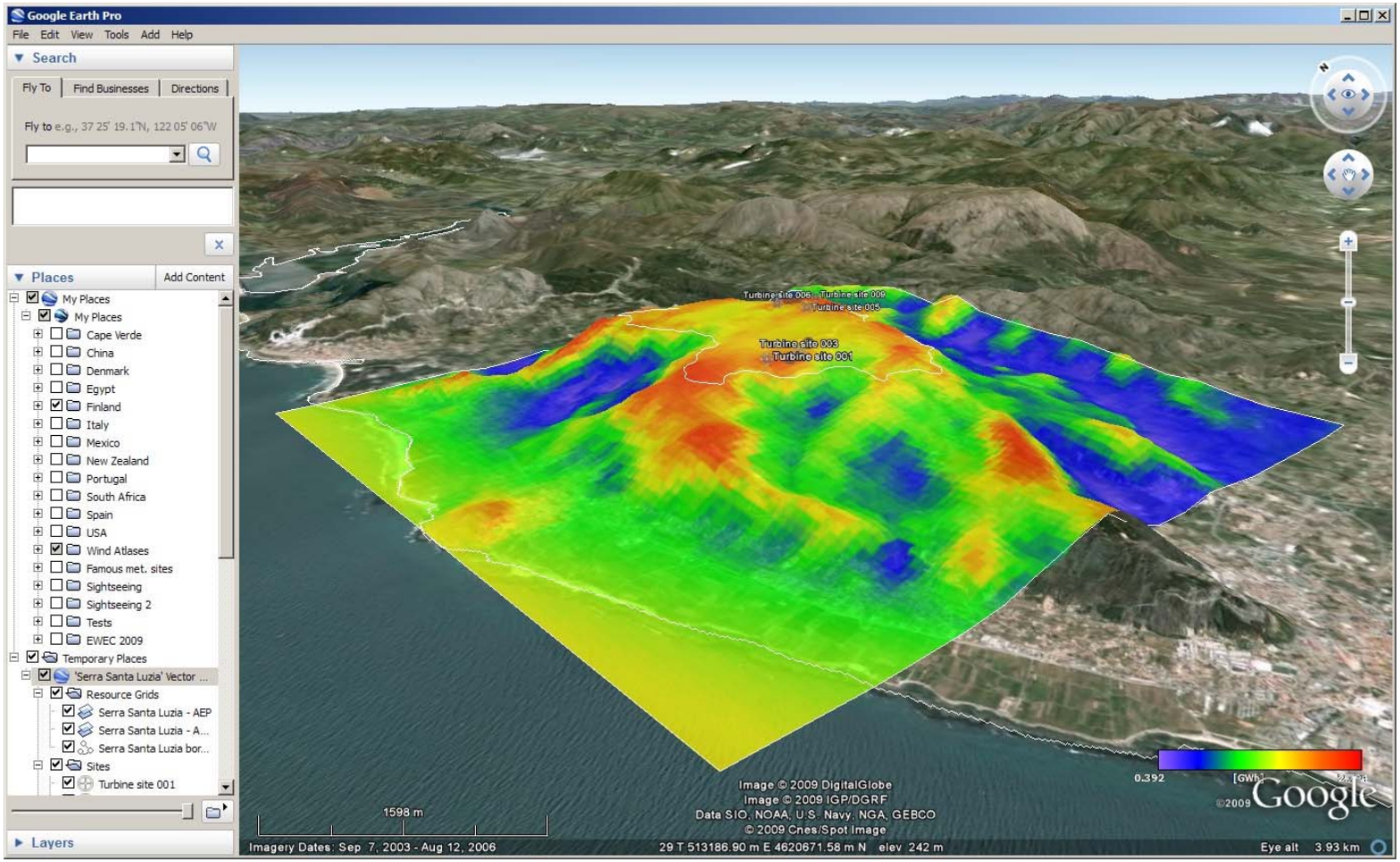
'Wind farm' Wind farm (29.654 GWh Net)

Settings | Site list | Statistics | WF Power curve

Site ID	X-location [m]	Y-location [m]	Elev. [m]	Rx [%]	DR	Ht [m]	U [m/s]	Grs [GWh]	Net [GWh]	Loss [%]
Turbine site 1	581498.9	4544508.0	820.0	24.7	2.7	50.0	7.08	2.627	2.534	3.51
Turbine site 2	581603.1	4544711.0	820.0	23.7	1.8	50.0	6.94	2.528	2.397	5.18
Turbine site 3	581679.9	4544903.0	802.5	23.9	1.9	50.0	6.69	2.368	2.234	5.66
Turbine site 4	581759.4	4545106.0	803.0	25.4	3.5	50.0	7.06	2.594	2.496	3.78
Turbine site 5	582173.4	4544179.0	890.5	22.2	0.2	50.0	7.29	2.704	2.597	3.99
Turbine site 6	582146.1	4544382.0	890.0	22.6	0.7	50.0	7.41	2.790	2.618	6.16
Turbine site 7	582220.1	4544571.0	880.0	23.1	1.1	50.0	7.48	2.801	2.645	5.6
Turbine site 8	582311.6	4544764.0	842.5	22.7	0.7	50.0	7.08	2.558	2.443	4.53
Turbine site 9	582357.2	4545048.0	820.0	23.8	1.9	50.0	7.14	2.580	2.478	3.96
Turbine site 10	582398.3	4545256.0	788.5	23.4	1.4	50.0	6.93	2.463	2.363	4.07
Turbine site 11	582453.1	4545448.0	769.8	24.4	2.4	50.0	7.04	2.529	2.419	4.32
Turbine site 12	582398.3	4545660.0	741.7	25.1	3.2	50.0	6.96	2.494	2.431	2.53

Calculate

The goal – wind resource and uncertainty maps



Kortlægning af verdens vindressourcer

Det har taget over 30 år, men endelig er vi ved at være der!

A history of wind atlases

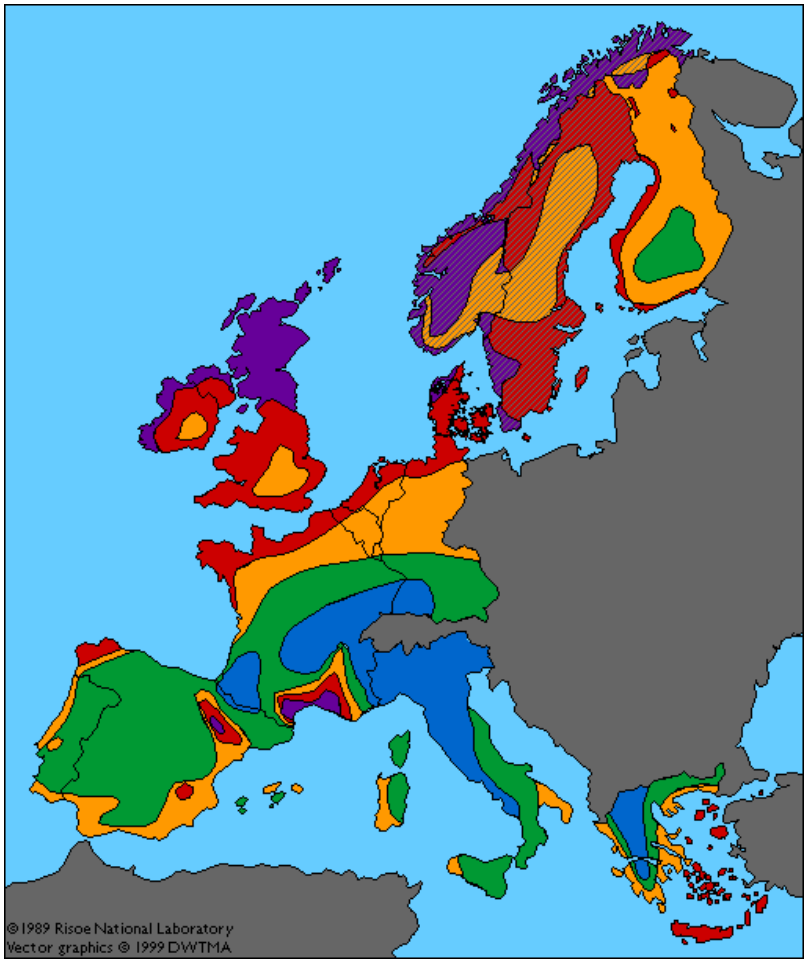
1979 – Wind Atlas for Denmark
- European wind atlas project (1981-)
- WAsP software released (1987)

1989 – European Wind Atlas (EU12)
- Atlas Vent de l'Algérie (1991)
- Wind Atlas for the Gulf of Suez (1996)

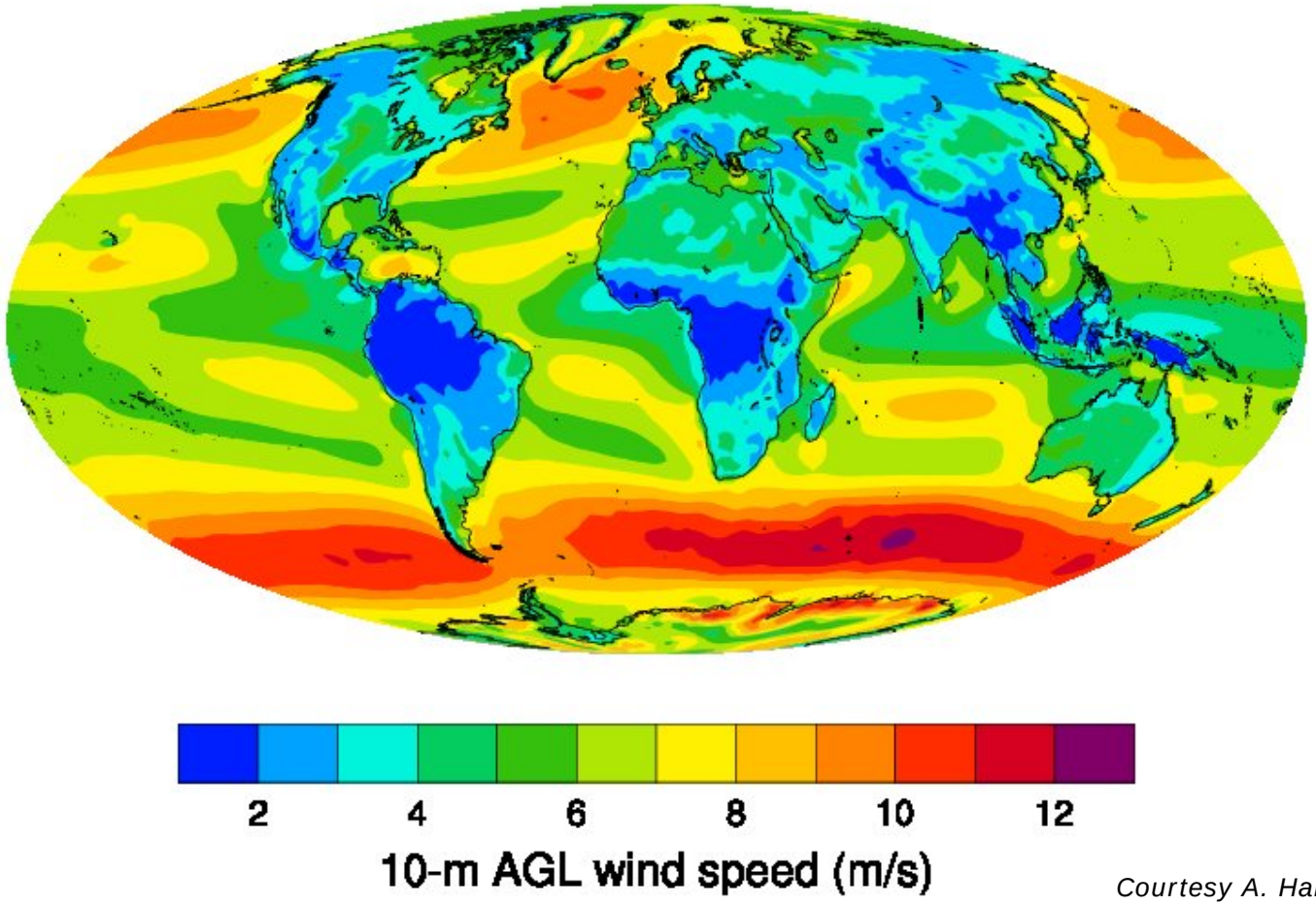
1999 – Wind resource map for Denmark
- Wind Atlas for Cape Verde (2002)
- Wind Atlas for Egypt (2006)

2009 – Wind atlas for Dongbei, China
- Wind Atlas for South Africa (2014)
- **Global wind atlas project (2015)**

2019 – Wind resource map for the World
- (Time for retirement?)

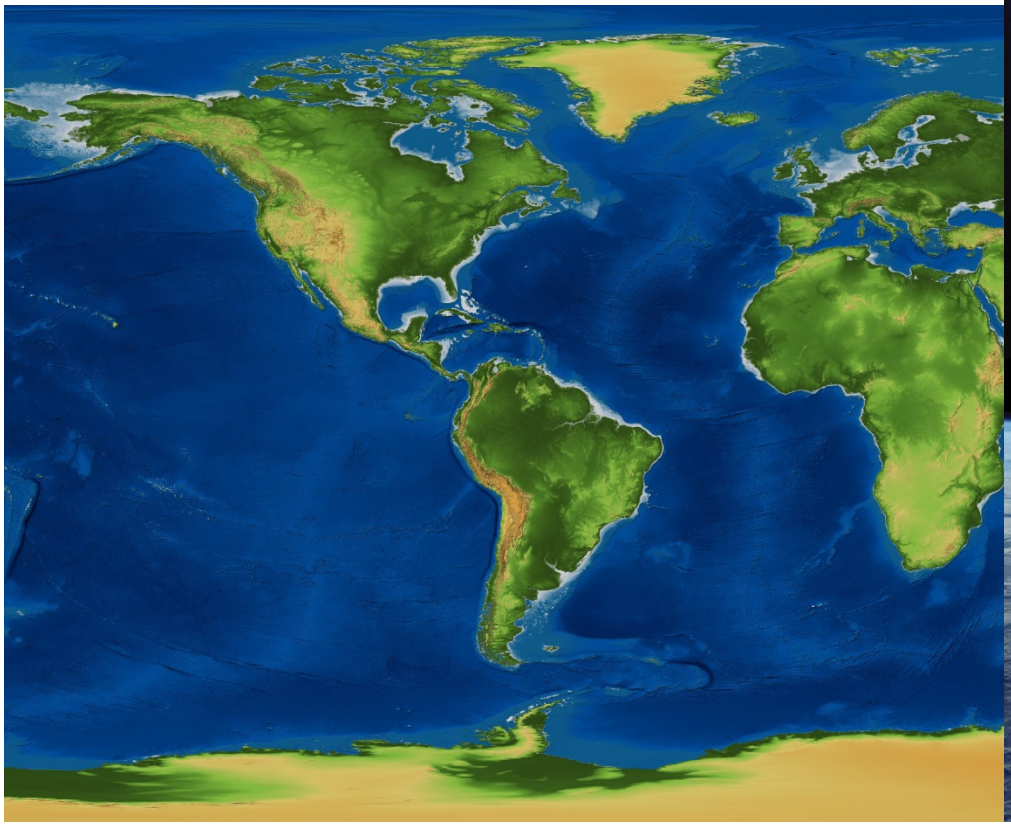


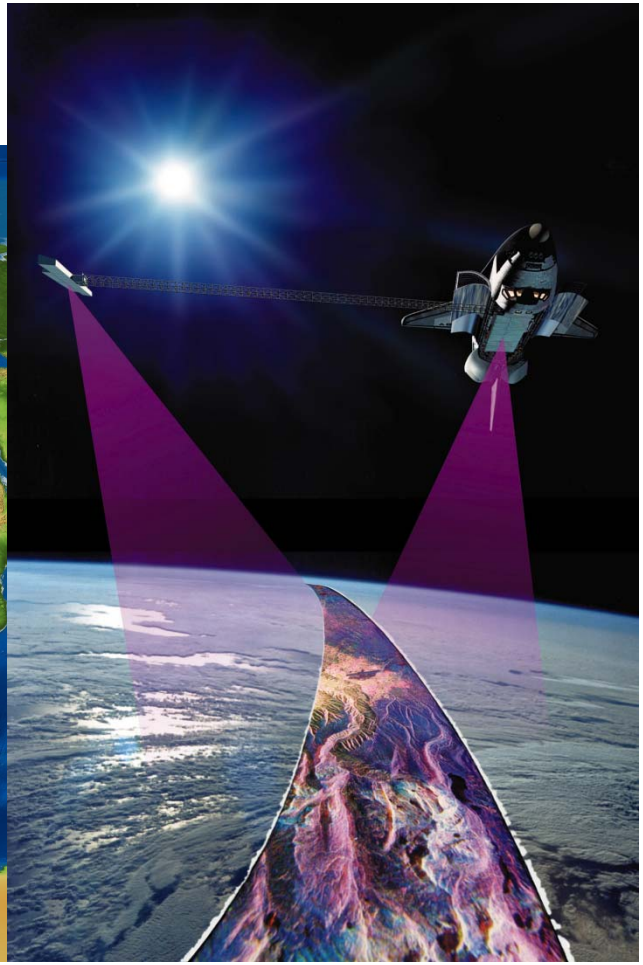
Average winds around the world



Courtesy A. Hahmann

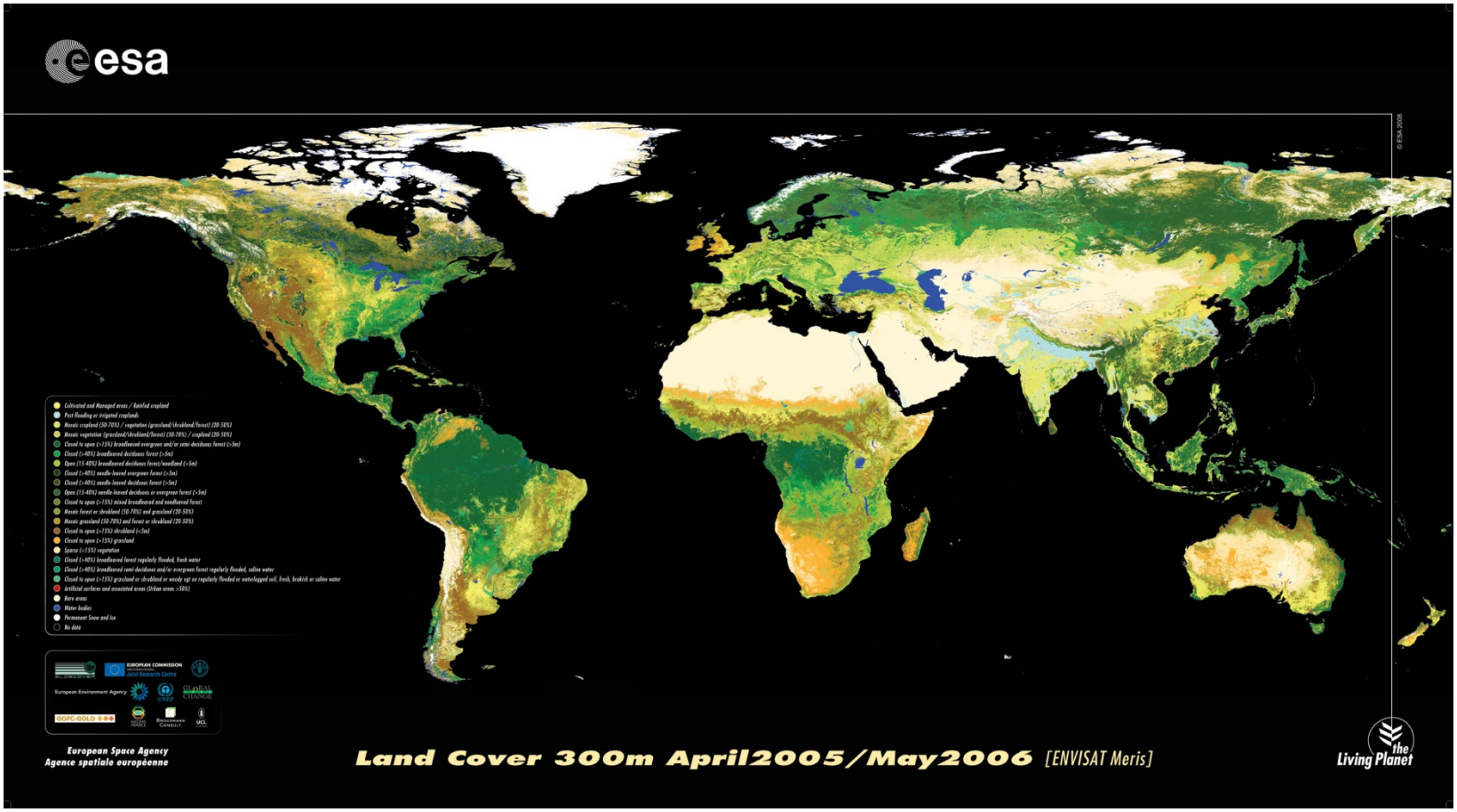
Elevation map of the world





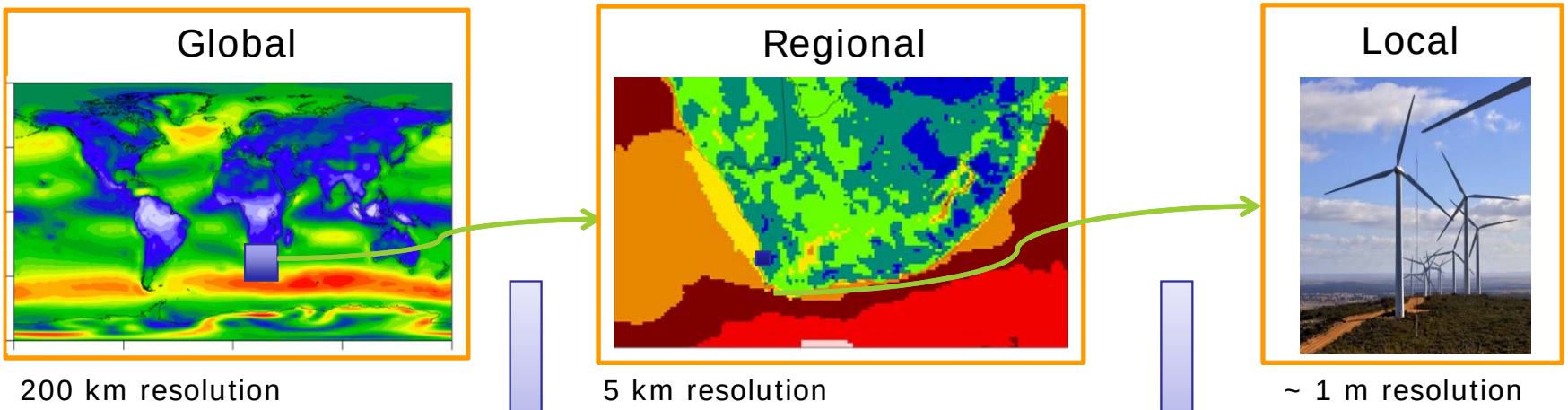
- High-resolution elevation and land cover from airplanes, space shuttle Endeavour and satellite observations.

Land cover map of the world

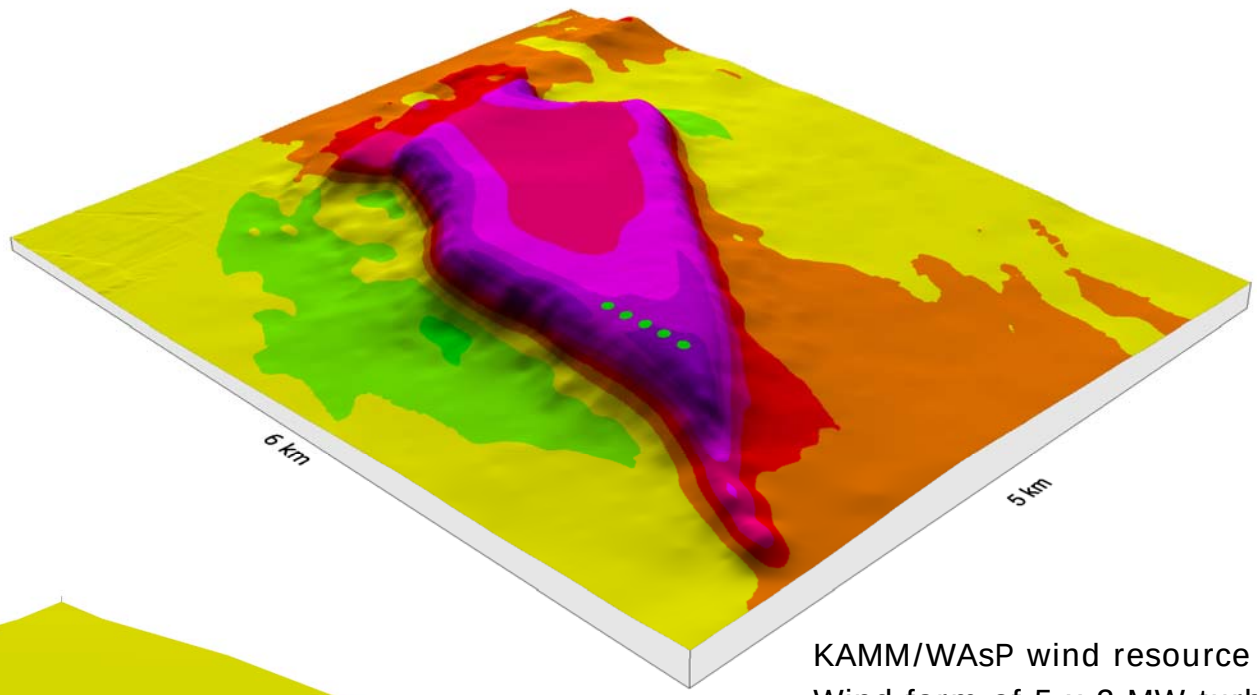


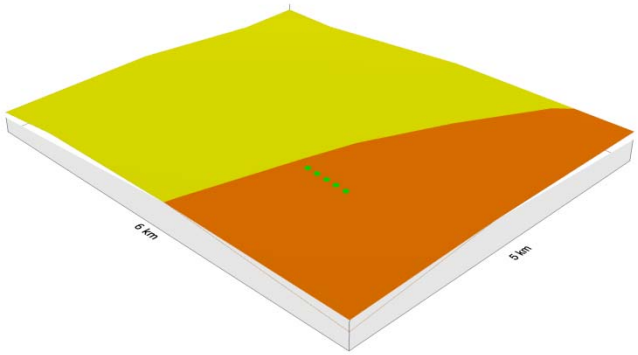
Global wind resource mapping methodology

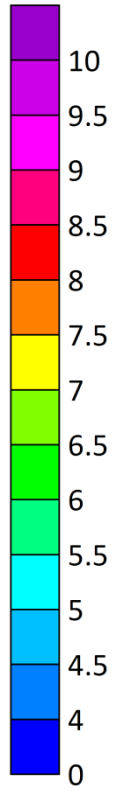
Downscaling from global reanalysis data, verification and use



Microscale vs. mesoscale: effect of resolution



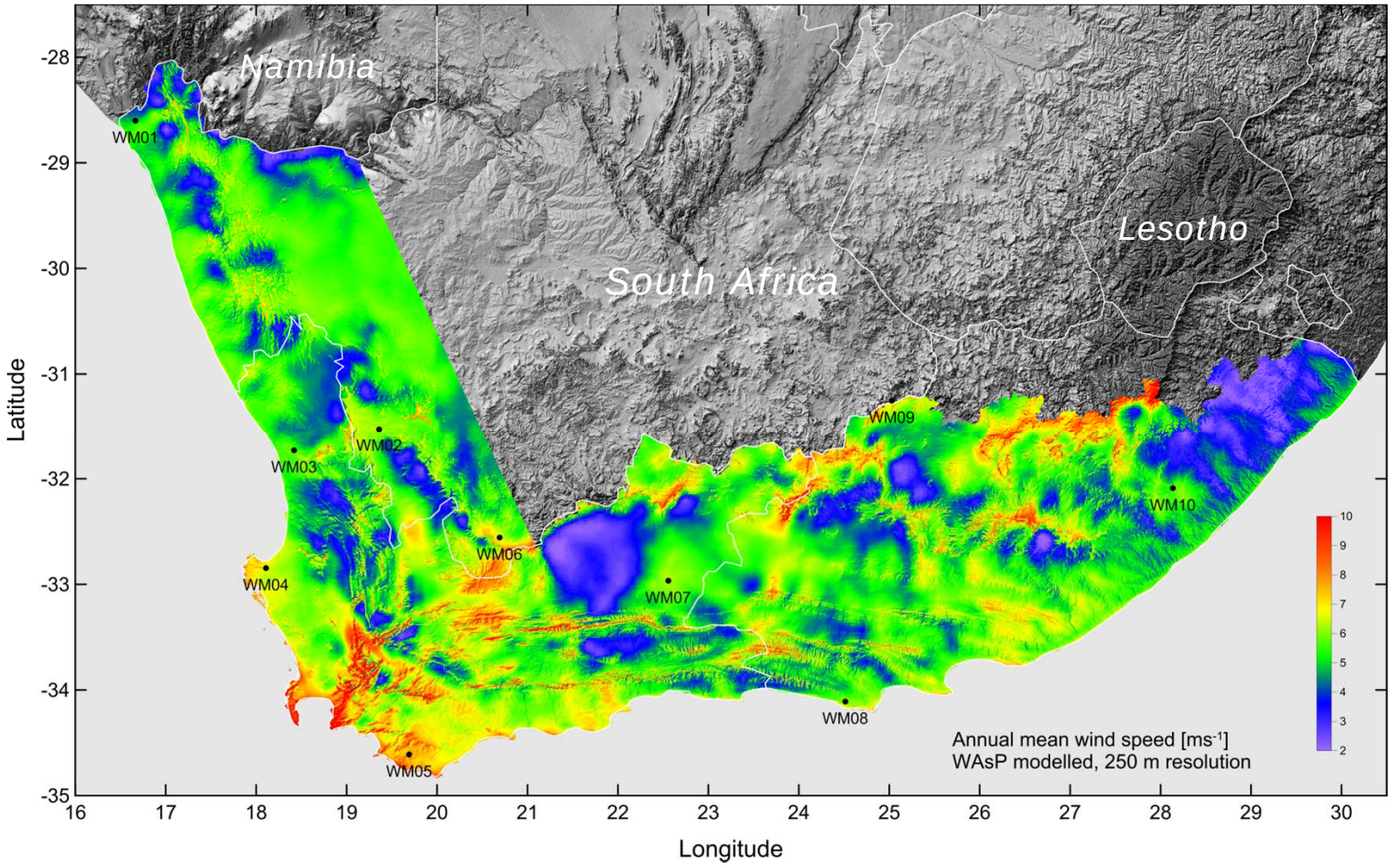




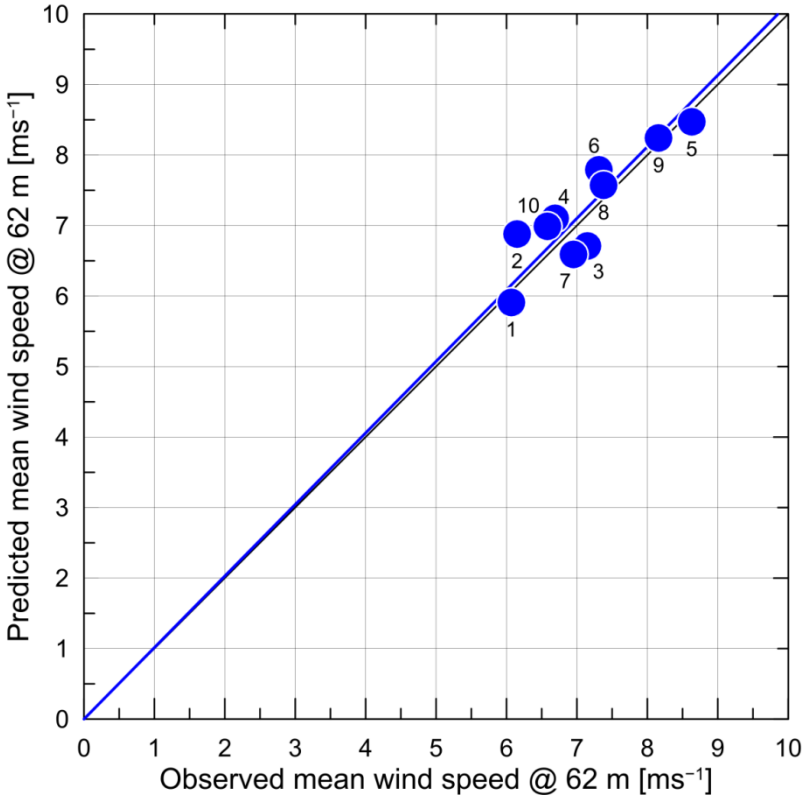
KAMM/WAsP wind resource map
Wind farm of 5 x 2 MW turbines

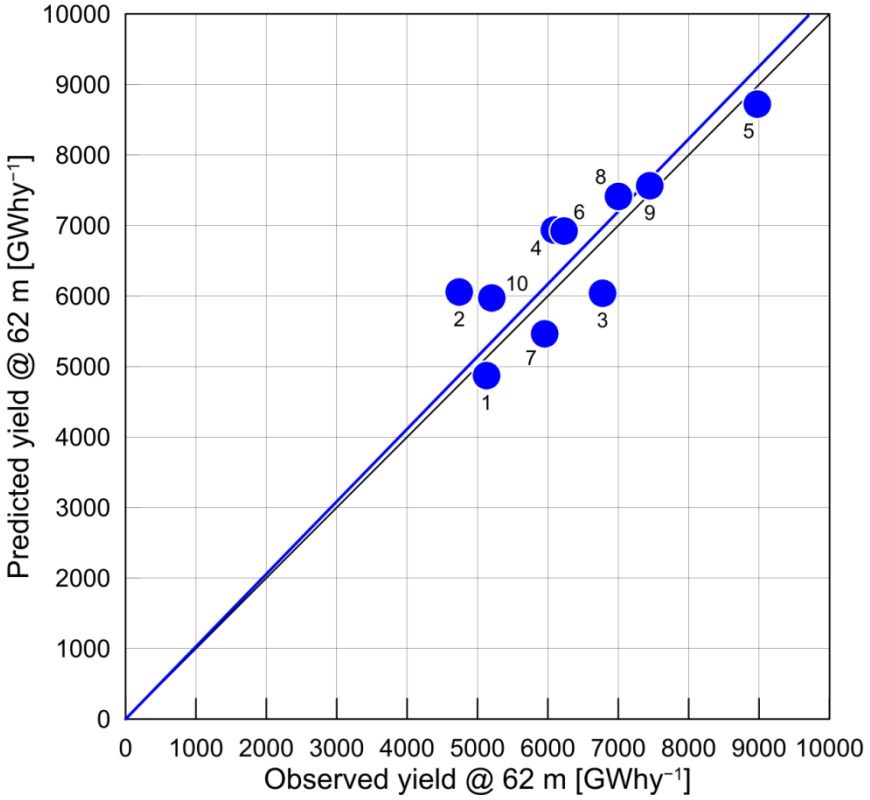
Grid cell size	Estimated AEP
20 m	55 GWh
5120 m	39 GWh

South African wind resource (wind speed @ 100 m)



Verification of methodology in South Africa



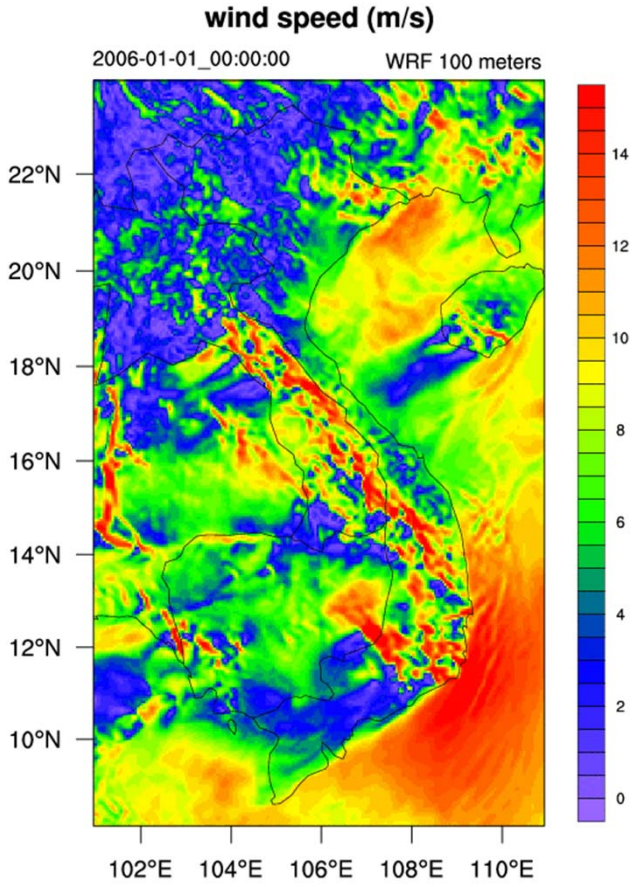


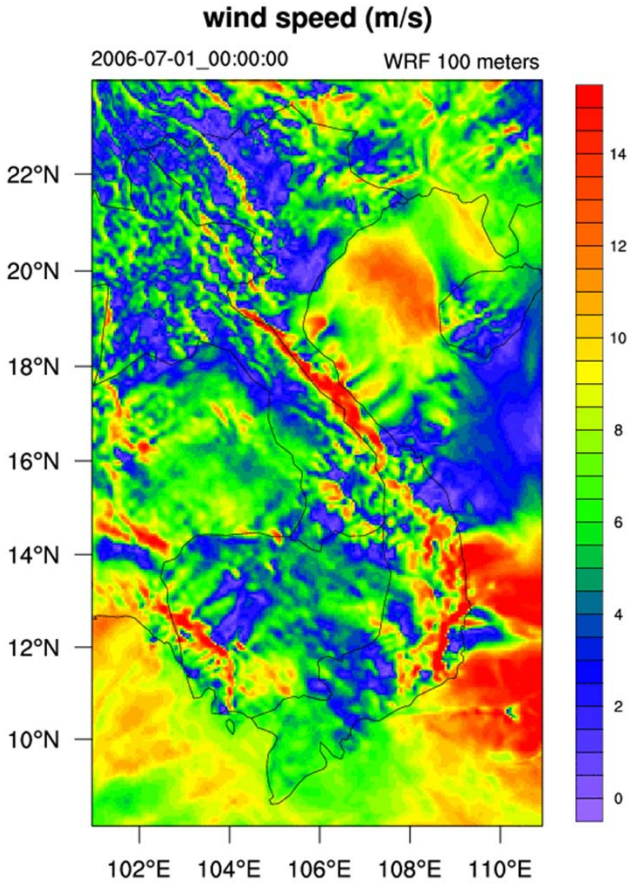
- Wind speed
  - Slope: 102%
  - Spread: 5.9%
- Energy yield
  - Slope: 105%
  - Spread: 12%

Mapping the worlds wind resources – quick recap

- Calculate annual energy production of wind turbine
  - Fundamental challenge is predicting the wind climate
- Wind flow modelling challenges
  - Temporal scales from 10 min to 20 years (in the future)
  - Spatial scales from 1 meter to 1000+ km
  - Computationally expensive (distributed computing)
- Wind resources of the world
  - Necessary data and modelling tools now available
  - First global attempt @ 250 m resolution in 2015 at DTU
  - Data in public domain for authorities, planners, investors, developers, power sector, industry, consultants, academia, …
- What's next?
  - Extreme winds
  - Turbulence intensity
  - Other flow characteristics

Wind flow over Vietnam (two seasons) during 10 days





Courtesy A. Hahmann